APPROACH FOR DETERMINING OPERATIVE COSTS IN A DYNAMIC ENVIRONMENT FOR DECENTRALIZED CONTROLLED PRE-STORAGE ZONE

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Abstract- Costs in dynamic environments especially in high complex pre-storage zones with hundreds of continuous conveyor systems and unpredictable shifts in arrival and departure time of goods is hard to determine. The dynamic behavior effects on the transportation times and therefore a direct effect on the automatized and decentralized control continuous conveyor system. Jamming and blocking results in non-continuous motor behavior, e.g. stop and go. Because high complex pre-storage zones are cost expensive a simplified model is presented able to calculate expectable costs for such system.

Keywords- Computer Integrated Manufacturing,Mechatronics and Automation, Production Planning and Control

I. INTRODUCTION

Internet of Things, cyber-physical systems or Industry 4.0 are expecting to offer different solution for the operation of many existing industrial systems as transportation or manufacturing systems [1]. Current approach focus on centralized control which lacks in scalability and flexibility, caused by the strict hierarchical order of control in pre-storage zones in warehouses. The building blocks for controlling each element in a pre-storage zones are already modulized, in hardware and software specifying the behavior of one element. But the interaction in one working group (several elements combined) has to be implemented manually due to the heterogenic project specific structure. Furthermore, logistic systems like the pre-storage zones facing different challenges, e.g. complexity in product individuality, dynamic in transportation and interaction between the goods, information's causing a higher communication effort due to the dynamics in transportation and hierarchical aspect each level solution or computation is depended on other levels [9]. Current issue in planning decentralized controlling of components in the pre-storage system is the uncertainty in investment and operative costs. To give an insight in a possible cost determination a simulation based approach is introduced. This paper is organized as follows. Section II introduces the background and the field of work. Section III gives an insight in related work. Section IV introduce the used method for cost determination and Section V the simulation structure for evaluation. Section VI gives a conclusion and further challenges in research.

II. BACKGROUND AND CURRENT STATE OF THE ART

2.1. System structure

Current decentralized controlled warehouse systems are distributed small logical units, which are capable to compute simple tasks to fulfill an overall goal.

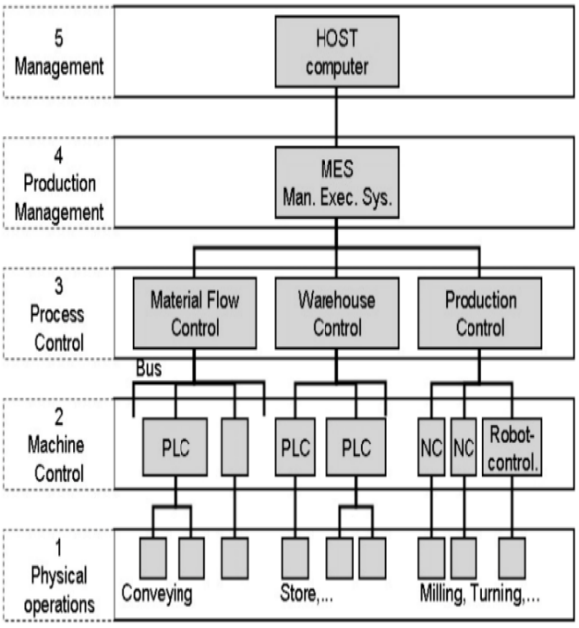


Fig.1. Current structure in automatized control [2, translated by 3].

Figure 1 shows the current automatized structure in hierarchical systems used in warehouses specialized in distribution. For transportation control of material level three the material flow control (MFC) down to level one for physical operations are mainly used for transportation.

Level three determines the route and organization of the route execution, communication with programmable logical controller (PLC) on level two. The route determination is based on the underlying algorithm which focus lays on a predefined factor during the project acquisition phase or planning phase in interaction between the warehouse provider and customer.

The interface is a bus (for the interested reader see [4], [5] or [6]) system which enables the communication between the MFC and the PLC on Level two.

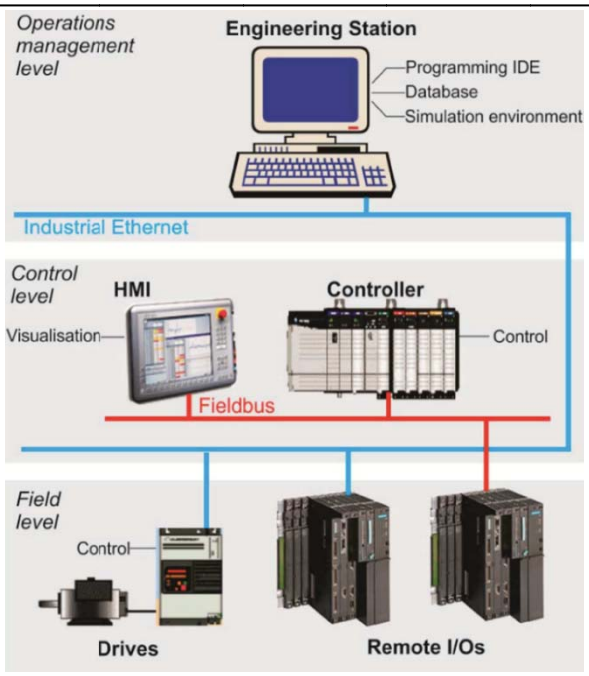


Figure 2. Hardware architecture of factory floor automation systems on machine control and physical operation level [7].

In Figure 2 devices are displayed for controlling the physical level e.g. conveyor, milling, turning, with PLCs (Control Level) by using external devices (Remote I/Os) to send and receive the analog / digital signals for the motor or the sensors to compute the actions in the next operational step.
This approach is strong hierarchical and needs high effort in customization in the planning phase and afterwards in build phase extensions.
Therefore, the current focus in research is the decentralization of the control at the PLC and MFC level to flatter the organization structure to increase the scalability.

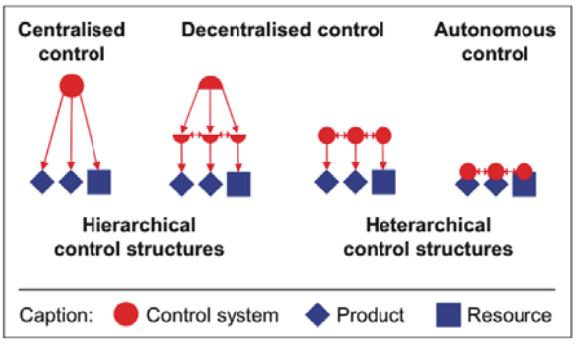


Fig.3. Harmonization of control structures [8].

Figure 3 shows the harmonization of the control structure from centralized hierarchical control structures to autonomous heterarchical control structures.
In contradiction to a hierarchical control structure in heterarchical control structures the system and his subsystems are autonomous. To ensure operability each subsystem has a specific degree of self organization and communication with his surrounding environment to enable the execution of higher task interacting with others.
In warehousing especially in the distribution of goods each subsystems consists of one control unit and one specific physical hardware for transporting, sorting or distributing the goods

2.2. System structure

For transporting only continuous conveyor with motor and binary sensor based on light are considered for controlling and in Section V for evaluation. The control unit is capable to parameterize the motor based on the sensor data and information's given by other transportation units. The sorting and distribution is done by right angle decks, capable to shift the goods in a 90-degree manner to other transportation units.
A PLC is the main control unit in industrial automation system. They are connected with the sensors and actuators via direct electric wiring to their input / output I/O ports or via remote modules [7].
In heterarchical structures the plc is directly mounted on the transportation unit and is wired with the I/Os, no remote modules are needed. The communication is done by real-time Ethernet capable protocols, like ProfiNET. Therefore the PLCs are connected with regular industry network cables to reduce the overall cost.

2.3. Cost estimation in dynamic environments

Warehouses focused on distribution with a small dwell time of goods are related to a cost estimation in the planning phase to estimate the return on investment.
Such types of warehouses have a high throughput and a high dynamic behavior in transportation of goods. The dynamic comes from interaction between the transportation goods by blocking each others. This blocking cumulates over the goods and can dramatically decrease the service grade of a warehouse.
Specialized routing algorithm ensure a deadlock free transportation to prevent system malfunctions.
The operative cost of a decentralized system is depended on the running cost of the transportation units, the waiting time and transportation of the units. Which can lead to a stop and go behavior with increased power consumption.
The routing algorithm used for determining the path during execution is a time-discrete decentralized opportunistic route algorithm. This routing algorithm is separated in three different parts: routing, communication and cost tracking, displayed in Figure 3.
The routing part (Figure 4) is a decentralized scheduler storing the arrival, estimated execution time and end time. The scheduler is receives his data based on the path finding algorithm which is based on the communication and cost estimation modules. The time slots in the scheduler are giving an expected

time a container could arrive and dependencies between other container to estimate deadlocks and for preventing deadlocks at a transportation unit. The execution of a container is done by a FiFo. When a container is arrived the transportation unit are checked if a deadlock could appear if this container is handled immediately. If a deadlock free situation exists the container will be handled. Otherwise a dependency to this specific timeslot will be stored and after all dependencies are resolved the container will be handled.

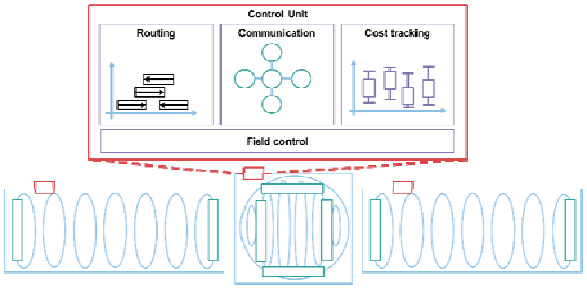


Fig.3. Routing algorithm in one decentralized PLC unit controlling a right angle deck.

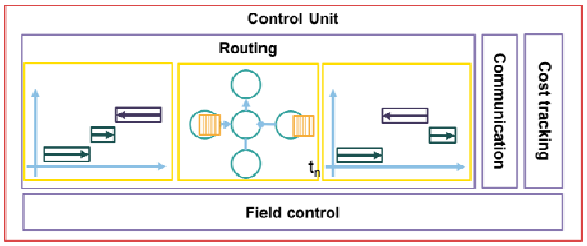


Fig.4.Routing module with decentralized Scheduler for container arrival estimation.

The communication module (Figure 5) handles the communication to other plc units in the system. Data packages are being forward to the destination or related on their specific task handled by the plc. The main task is path finding for a container entering the system.

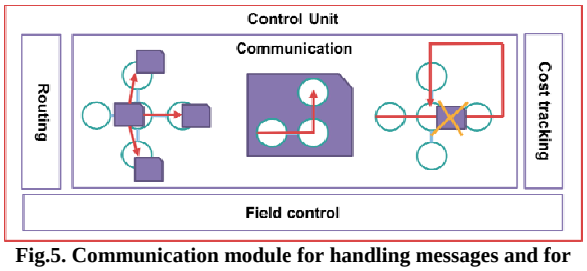


Fig.5. Communication module for handling messages and for path finding.

This is done by multicasting a message with the path already visited and added with the current estimated costs when using the transportation unit. If the message arrives at one sink which is not the destination the message will be dropped. If the transportation unit already computed the costs for one container, the message will be dropped too, to ensure a loop free path. If the message arrives at the destination it will be send back to the source, based on the stored path. The source itself waits for a determined time in prior for path and chooses the one with the lowest transportation cost.

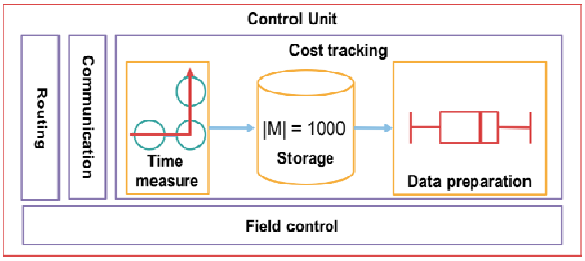


Fig.6. Cost tracking for dynamic cost adjustment based on the handling time.

The Cost tracking (Figure 6) module determines the costs for one transportation task done by the transportation unit. This is done by measuring the time over the lifecycle of the transportation unit in the system handling the container. If a cost estimation is needed for path finding the cost tracking module computes the lower quintile based on all stored data. The lower quintile ensure that the shortest path will be preferred instead of detours.

III. METHOD

This section describes first the composition of the overall cost for the system architecture. Then the static costs to determine the costs for the automatized decentralized control and last the used method for determining the costs occur during transporting containers in warehouses specialized in distributing.

3.1. Cost Composition for System Architecture

The cost composition describes the relation between the static and dynamic costs in automatized controlled pre-storage zones.

The overall cost is the sum of all fixed and dynamic costs, see (1).

(1) $$C_{all} = C_{fix} + C_{var}$$

with:

C_{fix} as the fixed cost, descripted in Section 3.2 and C_{var} as variable costs, descripted in Section 3.3.

3.2. Static Cost Determination

The static costs are the amount of hardware has been used for controlling and the wiring. Due to the adaptive nature in decentralized control a linear scalable behavior has been used as a cost determination.

(2) $$C_{fix} = P_i * X_i * M_j$$

with:

$P_i$as the costs for a decentralized control unit with wiring for the conveyor unit i.

X_i as the amount of control units used for controlling one conveyor unit i.

$M_j$as the installation cost for one control unit j.
Therefore, the fix cost for controlling is separated into the cost for one control unit, the amount of control units used and the installation cost for one control unit for one automatized conveyor.
The individual cost for implementation the control logic is not considered. As in adaptive systems, the implemented logic for communication and route finding based on transportation interfaces is the same on each control unit and therefore constant. The control logic of the actuator based on the sensors and route finding algorithm is conveyor specific. Each different task (e.g. bidirectional, unidirectional transportation or sorting) needs his own logic. For similar tasks and environment, the logic is reusable without the need of adaption.

3.2. Dynamic Cost Determination

Due to the structure of the elements and their fully automatized behavior this method is based on the activity-based costing [10] (ABC) instead of theory of constraints, due to the dynamic nature of container routing [11] in decentralized pre-storage zones.
In fully automatized pre-storage zones the motor behavior has the highest impact at the operative costs due to the energy consumption caused by starting and running the motor based on the parameters given by the routing algorithm.
Maintenance cost of the transportation units is not considered in the cost function.

$$\min(C(G)) \ \forall \ G_i \text{ in } P_{t-t+1} \tag{3}$$

$$C(G) = \sum_{i=0}^{n} \varphi_i \tag{4}$$

$$\varphi = GxM \tag{5}$$

The goal is to minimize the costs (3) for all goods transported in one-time period on all transportation units. Therefore, the overall cost for one period is the sum (4) is the cost of the subset (5) of containers on transportation units motors used.
All containers in one period are considered, because of the dynamic in the system given by blocking of the containers and the needed state changes of the transportation unit for handling.
The cost function is used for determining the path a container is using during transportation execution. The transportation time of one container over one transportation unit is (6).

$$T_i = \sum_{j=0}^{n} S_{i,j} + \frac{L_i}{V_i} + \frac{V_i}{P_t A_i} \tag{6}$$

The transportation time consist of every state change $S_{i,j}$with i as the transportation unit and j every state. A transportation unit has to execute at least three state changes to handle the good. In prior a state change to pick up a container from the previous transportation unit, a state change to for transporting the container over the transportation unit and a state change to pass the container to the next transportation unit.
The second term describes the approximated linear time a container needs for the movement with L_i as the length of the transportation unit i, V_i the velocity and A_i the acceleration given by the parameters P_t from the routing algorithms at time t.

IV. EVALUATION

The evaluation is done by simulating a distribution center handling goods for container. It purpose is fast handling and commission of goods arriving at the inbound and sorting for the outbound.
The distribution center is the center in hub and spoke organized supply chain systems. The good is, when needed, only stored for few days before leaving the center. To reduce the costs and increase the service level of the center a high efficient route finding algorithm has been used. This evaluation focus on the static and specially the caused dynamic costs in transportation by the routing algorithm.

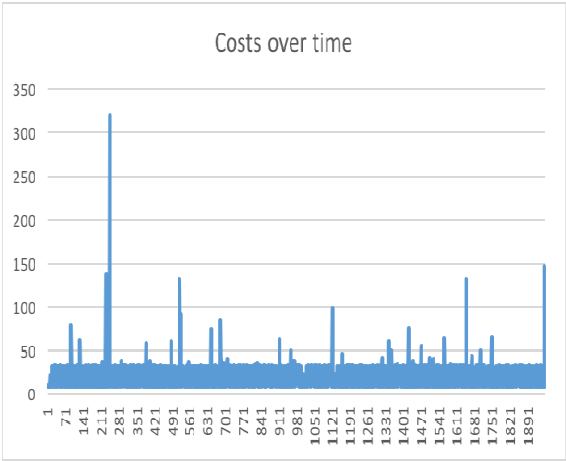


Fig.6. Costs during runtime of the distribution center.

Figure 6. shows the costs caused by the routing algorithm. The costs have a maximal cap which can be interpreted as the worst case cost scenario for a specific period based on the maximum amount of goods at inbound and needed goods at outbound.

CONCLUSION

It could be shown that the dynamic costs can be approximated and reduced to the energy costs caused by the routing algorithm. Minimizing the dynamic costs in route finding reduces the overall costs for one pre-storage zone like used in distribution centers.
Further work focus on cost optimization in route finding with constraint in service level. The static costs are negligible compared to the dynamic costs during runtime if considered that a distribution center is running for several years.

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